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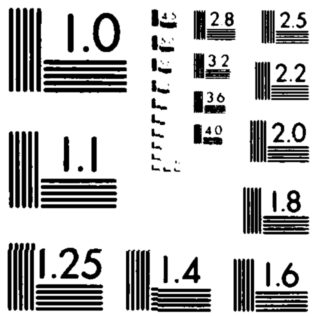

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FLAW CLASSIFICATION IN WELDED PLATES WITH A MICROPROCESSOR CONTROLLED FLAW DETECTOR

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by

Joseph L. Rose
J. Bruce Nestleroth
Edward G. Poplawski

Mechanical Engineering and Mechanics Department
Drexel University, Philadelphia, PA

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ABSTRACT

The purpose of this paper is to manifest that a microprocessor, when utilized in connection with an ultrasonic flaw detector, can reliably regulate an ultrasonic inspection process. By virtue of several concentrated laboratory trials and accompanying analysis with the microprocessor-flaw detector combination, it will be demonstrated that dependable, speedy, and cost effective flaw detection is within the realm of reality.

Specifically, this particular study focuses on the microprocessor controlled evaluation of steel plates. While it is true that the overall procedure employed here involved itself with flaw classification in one area (welds in steel plates), it will become apparent that applications are not restricted to steel plates. Cognizant of this fact, this paper will also provide insight into other areas pertinent to the study.

INTRODUCTION

Previous studies [1] have sharply pinpointed the need, and advanced a potent argument, for the inclusion of microprocessors in ultrasonic inspection processes. Prompted by such encouraging findings, it became evident that the goal of implementing a microprocessor controlled flaw detection system ought to be pursued.

Satisfactory completion of this task immediately required that adequate test specimens, as well as suitable supporting apparatus, be secured. The former consisted of six welded plates provided by Krautkramer GMBH, a concern located in Germany. The plates, fabricated by the Voest Company in Austria, contained a variety of weld defects ranging from root and porosity imperfections to crack defects. The latter was comprised of a KB6000 ultrasonic flaw detector and an LSI-11 microprocessor.

Previous endeavors [1] had suggested that computer assisted data acquisition and pattern recognition analysis, when applied to the signals returning from various reflectors contained within the plates, could be of value in signal classification. In this case, however, the problem was to link the LSI-11 with signals from the plates relayed by the KB6000 in a reliable and swift ultrasonic inspection scheme. Moreover, provided this important objective could be reached, a fundamental, but vital, question had to be addressed: Were results furnished through utilizing the LSI-11 compatible with those yielded from experiments typically conducted with a large minicomputer (here, a PDP-11/05)? An affirmative answer to this query would confer an air of confidence in microprocessor controlled flaw classification capability.

PROBLEM APPROACH AND CONSIDERATIONS

Several approaches are possible for a study of this nature. Two very appealing, and probably most appropriate, methods will be related here. The first consists of a variety of techniques in which multiple ultrasonic probes are used, while the second incorporates only one ultrasonic probe. The primary difference in these two techniques is that utilizing multiple probes allows an individual to analyze more than one signal at a time, whereas one probe permits analysis of only one signal at a time. This last approach is often easier, and as various publications indicate [2], has become a very standard and popular procedure. Essentially, because of the factors of <u>versatility</u> and dependability involved, this study was conducted mainly on the basis of method two. However, it was decided not to totally eschew method one, since it is potentially a very potent contributor to defect analysis. Thus, some results yielded by using it are contained in Appendix II at the end of this paper. Yet, the main body of this report will address the study from the viewpoint of method one.

The basic mode of approach for this study rests on signal analysis from one ultrasonic probe, and is illustrated in Figure 1. Ultrasonic signals returning from a welded plate specimen are received by the KB6000 ultrasonic flaw detector, and then directed to either of routes one or two. Route one may be termed the standard route: Upon leaving the KB6000, signals are digitized by an analog to digital (A/D) converter, and subsequently processed by a PDP-11/05 minicomputer, Programs within the PDP-11/05, in turn, extract relevant information, displaying it on a video terminal. Route two can be classified as an atypical road. Here, specific adjustments performed on the KB6000 allow a digitized signal to be taken directly from the KB6000, processed rapidly by the LSI-11, and finally output on a video terminal or other appropriate device. A detour through the A/D converter is thus avoided.

The aforementioned approach is not very worthwhile unless the objects to be tested substantiate the need for its usage. In other words, it was not sufficient merely to have obtained specially fabricated welded plates; then, automatically subject them to rigorous testing. In depth examination may have been unnecessary. For this reason, several echoes returning from the plates were scrutinized visually in an attempt to denote a signal representative of a particular defect. Efforts to distinguish the various waveforms proved fruitless, since many of the signals from different kinds of defects were identical. (See Appendix I). It thus became apparent that a more substantial evaluation was apposite. Accordingly, a series of experimental exercises using both routes followed.

The PDP-11 and its counterpart for the experiment, the LSI-11 had the task of processing large amounts of acquired data. Specifically, within both units are housed various programs that render an assessment of digitized data. This evaluated information is called a "feature". Essentially, a feature is some characteristic of a signal that permits one to differentiate one signal from another. Logically speaking, if one can find something inherent in a signal from a crack defect that consistently differs from that of a root defect, he has obtained the capability to isolate crack from root imperfections; or, discovered a "feature", so to speak.

The features selected for this study have their foundation in those principles of the physics and mechanics of wave propagation which are applicable when waves travel through the welded plates and flaws in question. The first feature examined was rise time; namely, that time associated with the abruptness of return as echoes from the plates reach the receiving ultrasonic transducer. Since a crack is somewhat specular in nature, the rise time is somewhat smaller than that for a porosity. The concept of fall time is also often invaluable and served as a second feature in this study. The reason lies in the fact that fall time is somewhat larger for a porosity defect, because of the dispersive

character of the waves as they reflect from a porosity cluster. The third feature selected was pulse duration, which for reasons previously explained, is shorter in the case of a crack than for a porosity. (See Appendix I for sample features.)

Another feature chosen for this analysis was that of examining mode conversion and scattering as ultrasonic waves travel from a given flaw. Essentially, mode conversion is a term signifying a change in ultrasonic energy distribution as ultrasonic waves travel from one material to another. Earlier work had implied that the mode conversion character at a crack tip, as well as the superposition from scattering off crack tips, was somewhat more pronounced than for a smooth or circular defect. Consequently, a shear wave reflection from a crack tip can be evaluated with respect to the different wave components from a crack. In order to take advantage of possible knowledge given from mode conversion and wave reflection, two gates (see Figure 2) were positioned on the KB6000 display screen. This permitted observation of the principle echo from the defect, as well as the secondary wave propagation from the given flaw. Also, it was now feasible to examine wave reflection from both edges of a crack. From a statistical standpoint, this feature was interpreted by relating the peak to peak (PK-PK) value of the signal in gate one to the PK-PK value of that in gate two, supplemented by another feature linking the PK-PK value in gate one to a root-mean-squared (RMS) value in gate two. Alternative approaches could also have been used which availed themselves of many other statistical features. Nevertheless, it is anticipated that the overall outcome would not be influenced positively or negatively.

Finally, after all pertinent feature information had been analyzed, it was packaged in two computer algorithms; one for the LSI-11 system, the other for the PDP-11/05 minicomputer. Subsequently, the algorithms were tested on all defects within the weld plates, not only to validate the algorithms themselves, but to critique the performance of routes one and two. The results of this comparison are presented in a following section.

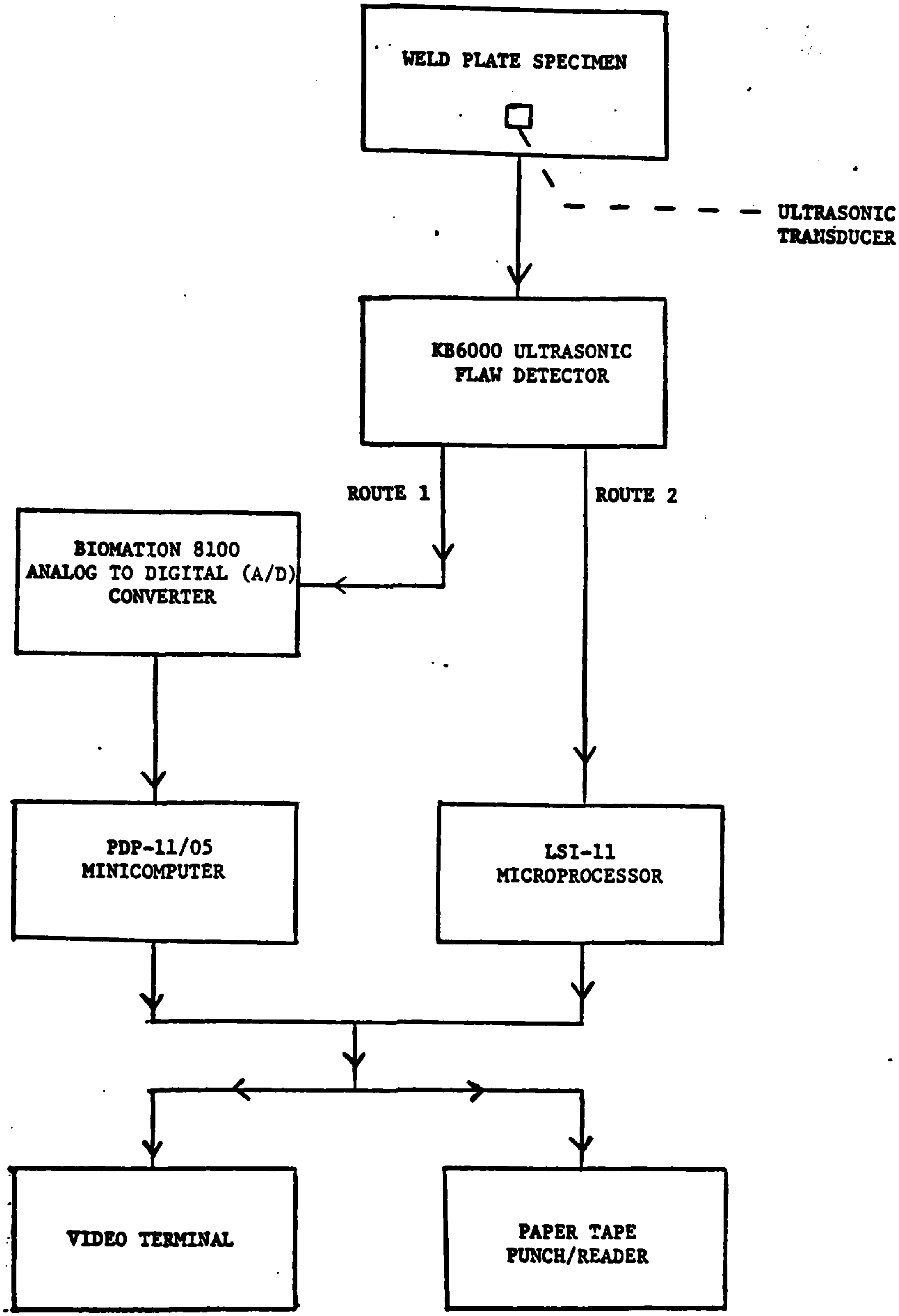

FIGURE 1 - Operational structure

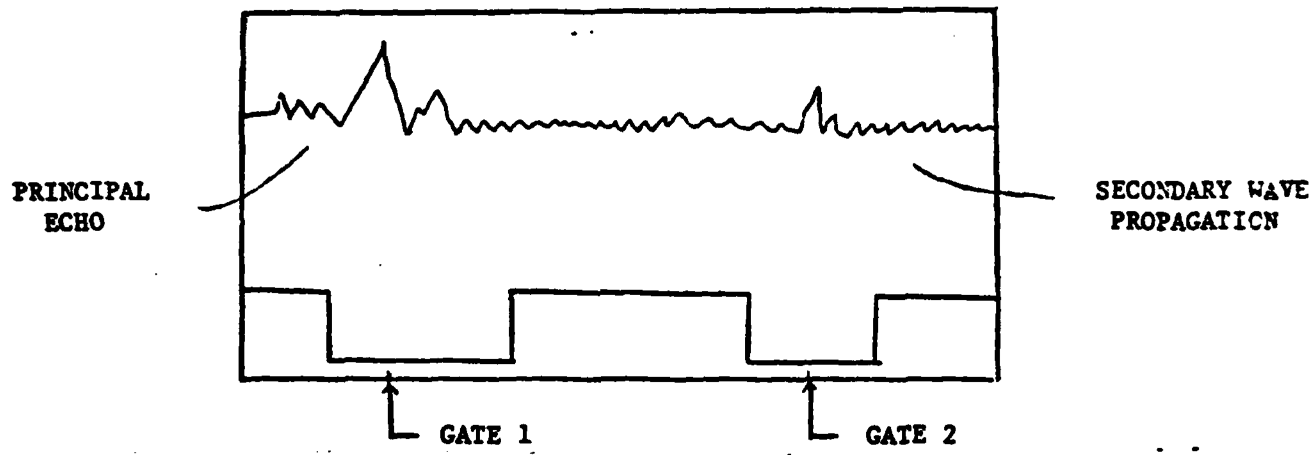

FIGURE 2 - KB6000 display

BASIC EXPERIMENTAL PROCEDURE

Data acquisition and Analysis Protocol for the System with A/D Converter

1. Calibrate ultrasonic transducers; perform necessary adjustments to ensure optimum performance of all equipment required for the weld plate analysis.

2. Examine the radiograph representative of each weld plate; meticulously scan appropriate sections of each specimen in an effort to determine where to concentrate the data gathering process.

3. For each weld plate specimen judiciously select a number of points at which reliable data can be acquired; correlate and compare points selected via ultrasonics with radiographic evidence.

4. For each plate formulate a diagram (grid system) which is essentially comprised of those points chosen for data acquisition.

5. Following the grid system, place an ultrasonic transducer on one grid point at a time, observing the signal appearing on the KB6000 ultrasonic flaw detector.

6. Adjust the gain and other instrument controls in order to best display the signal.

7. Set the first gate such that the first signal (not counting the main bang) is contained within the gate.

8. Prepare Biomation 8100 A/D converter to digitize the analog signal visible on the KB6000.

9. Analyze the digitized signal appearing on an oscilloscope in order to confirm that the signal of interest was indeed digitized.

10. Once satisfied with the digitized representation of the analog signal, via the PDP-11/05 minicomputer, average the digitized signal eight times so that any noise effects inherent in the signal are minimized. Set the sample rate for the A/D converter at .02 μs.

11. Via the PDP-11/05 minicomputer, obtain the enveloped waveform of the averaged signal; extract apposite features (characteristics) of this enveloped signal for future comparison with the envelopes of other signals.

12. Repeat steps 5 through 11 until a reliable data base is developed for each plate.

13. With the data base procured in step 12, secure feature files for the following defects: crack, porosity, root,

14. Via the PDP-11/05 minicomputer, compare feature files with one another, thereby finding out what features can be utilized to distinguish defects.

15. After amassing those features which discern one flaw from another, develop a computer algorithm that contains these features and can predict one flaw from another,

16. Test the algorithm on the specimens.

Data Acquisition and Analysis Protocol for the KB6000 System w/o the A/D

1. Follow steps 1 through 7 of protocol for the system with the A/D converter.

2. Make sure the first signal is inside the first gate with the leading edge of the gate as close as possible to the start of that signal.

3. Run the program KB-DATA on the PDP-11/05e. The program will ask the operator to enter the delay value of the first gate. Upon entering that value, the program will:

(a) set the appropriate gates

(b) sweep the signal of interest

(c) extract features

RESULTS

This exercise clearly indicated that defects (root, crack and porosity types) concealed within the welded plate specimens could be distinguished from one another by data acquisition and pattern recognition analysis; either by incorporating the procedure applicable to route one or that appropriate for route two. A sample two space scatter diagram, shown in Figure 3, cogently affirms that the process of feature extraction can establish lines of demarcation between the various imperfections. Statistically speaking, Figure 3 infers that it is possible to achieve a larger range of sensitivity and specificity values depending on one's inspection goals. Here, a sensitivity oriented goal would simply be one which desires to locate as many of the existing cracks as possible - to become more "crack sensitive" so to speak. On the other hand, an objective of augmenting specificity would lean toward more non-crack, roots and porosities. Quite naturally, a predilection toward increasing sensitivity could very well decrease the specificity value, since some of the non-crack areas would be deemed crack areas in this sensitivity emphasized technique. Note that a marked tilt toward enhancing sensitivity does not necessarily usher in declining specificity. For alternative two space scatter diagrams and their accompanying different decision surfaces can be developed. These in turn could indeed improve the given computer algorithm used for the flaw classification problem to the point where both better sensitivity and specificity values are achieved. Figure 4 consists of a table of sensitivity and specificity values compared with the amount of data points taken by following the scheme outlined in route two. Here, it can be seen that a larger amount of data sets was instrumental in enhancing sensitivity without adversely influencing specificity.

Gratifyingly, the results procured by routes one and two were in quite reasonable harmony. This discovery is indeed significant since it means that

route two, while more versatile from an inspection standpoint than route one, also exhibits the same degree of excellence in performance accustomed to by using route one. Figure 5 contains a sample figure which demonstrates this proximity. The solid line holds for route one and the dotted line for route two. The former repeatedly appeared below the latter due to certain electronic constraints inherent within the latter. The deviation between techniques, however, is minimal; often no more than a few percent, as show in Figure 5.

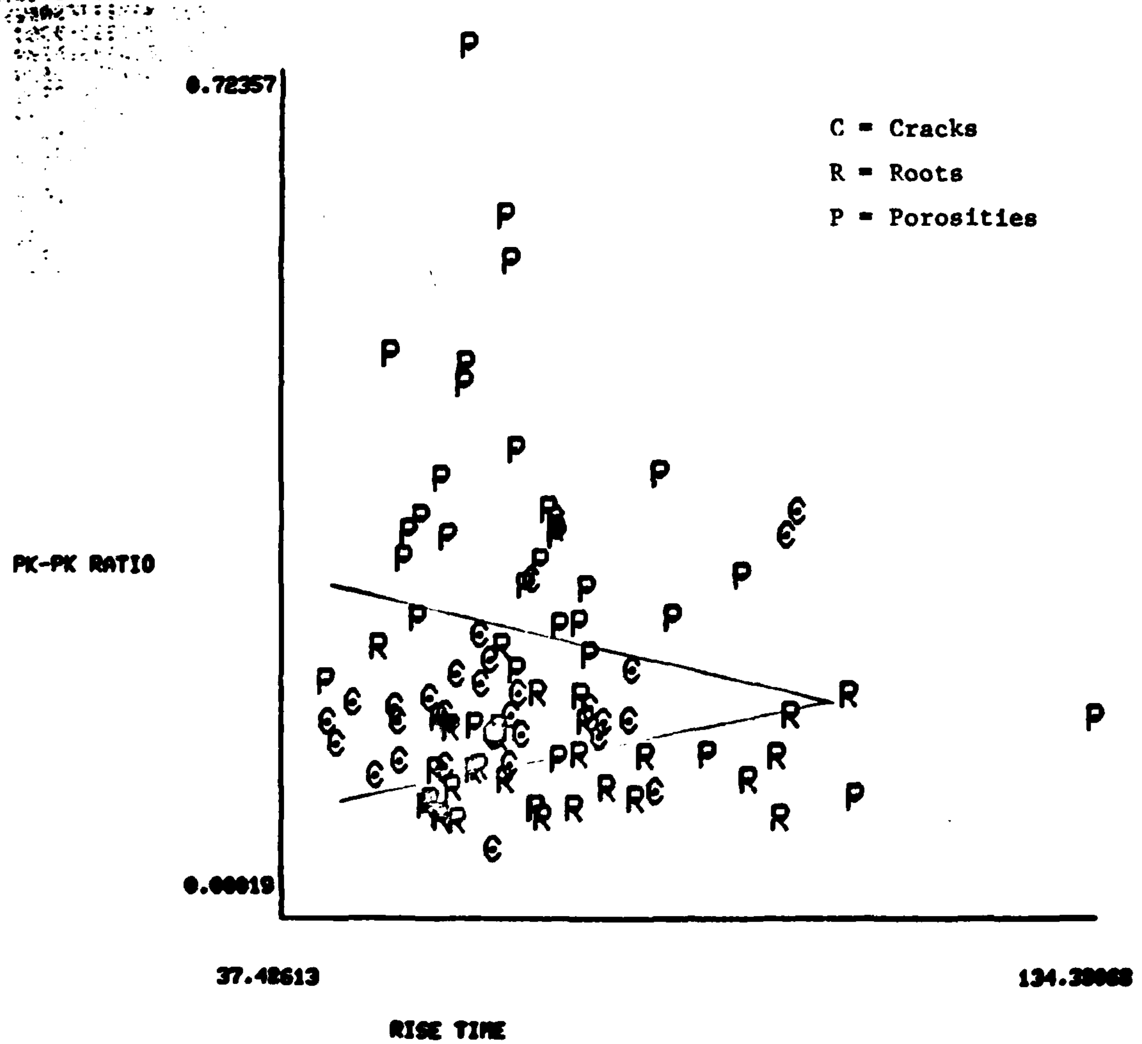

FIGURE 3 - Sample Two Space Diagram Showing All of the Data
(33 Cracks, 34 Roots, 33 Porosities)

	2-space Plot 42 total signals	2-space Plot 100 total signals
Sensitivity (finding cracks)	89%	93%
Specificity (finding non-cracks, roots and porosities)	75%	75%

FIGURE 4 - Best Results

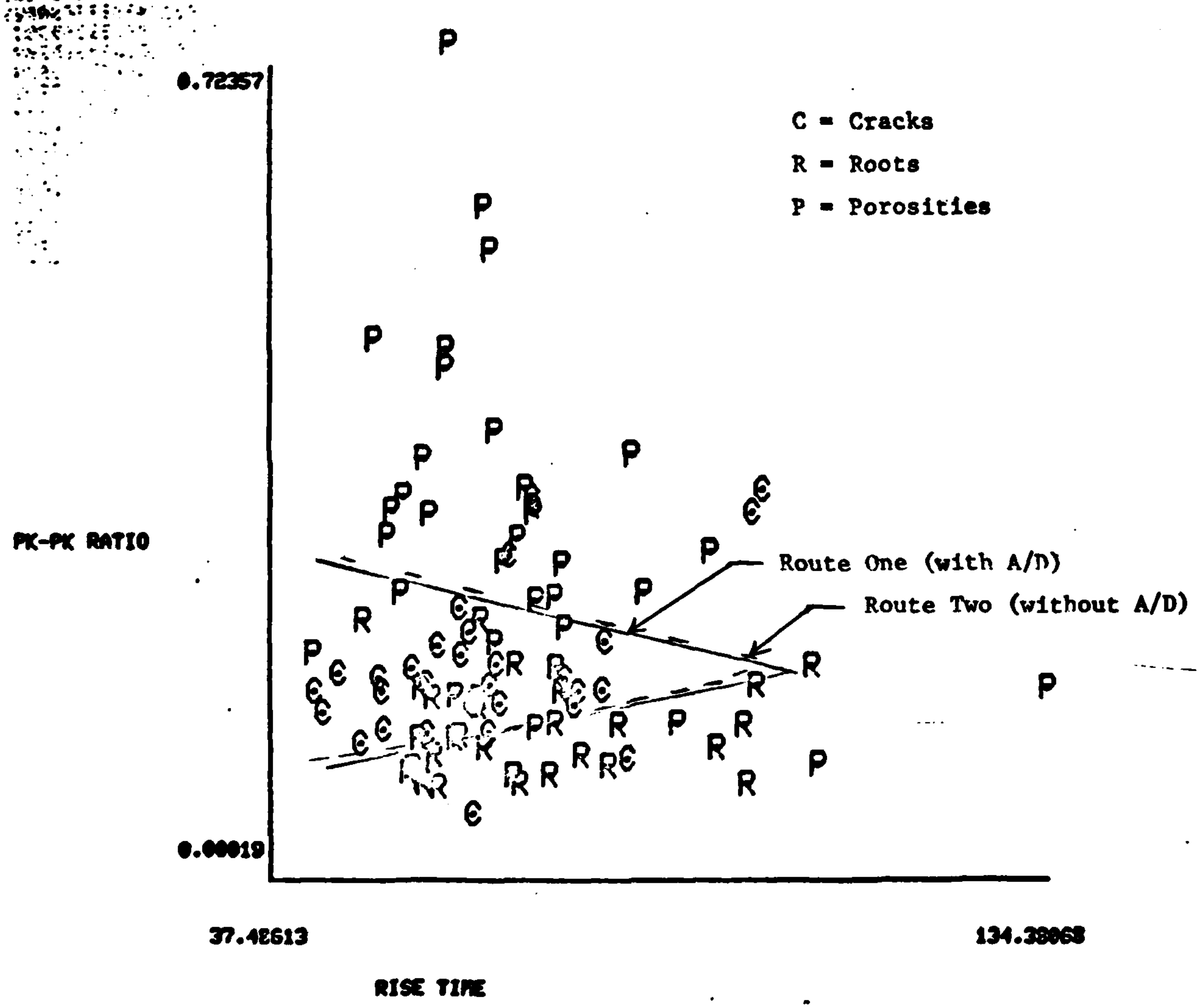

FIGURE 5 - Sample Two Space Diagram Showing All of the Data
(33 Cracks, 34 Roots, 33 Porosities)

CONCLUSION

In this study the microprocessr emerged as a valuable and dependable tool for controlling an ultrasonic inspection process successfully. Much versatility was gained by eliminating the necessity to follow the standard procedure of data acquisition and pattern recognition analysis, stipulated in route one. Additionally, the microprocessr directed arrangement exhibited the capability to closely mirror the results of the standard technique. These two driving forces of versatility and reliability argue persuasively for its inclusion in a broad range of ultrasonic inspections.

For instance, the fundamental modes of operation which evolved from this study could be of use to the nuclear industry; an area where the detection of intragranular stress corrosion cracking is of tremendous concern. Also, it is not hard to envision uses for the steel, automotive and shipping industries. Bluntly speaking, it appears that the possibilities for application of the technique expounded on in this paper are unbounded. However, one caveat is in order. Superb results demand excellent laboratory specimens. For although a computer control experiment allows data to be examined in an objective and consistent fashion, the results are only all encompassing as far as the test objects are concerned. In other words, unrealistic and/or incomplete test specimens can limit the applicability of the computerized solution to real problems. Thus, if an algorithm is ever to be implemented successfully in field testing, good training specimens are required.

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1. Rose, J. L. and Thomas, G. H., "Microprocessor Utilization in Ultrasonic Nondestructive Inspection Systems," Materials Evaluation, January 1980, pp. 69-76.

2. Rose, J. L. and Singh, G. P., "A Pattern Recognition Reflector Classification Feasibility Study in the Ultrasonic Inspection of Stainless Steel Pipe Welds," British Journal of Nondestructive Testing, November 1979.

APPENDIX I

Sample RF Waveforms from Porosity, Root, and Crack Defects, Together with Computed Algorithm Prediction Based on the Given Signal

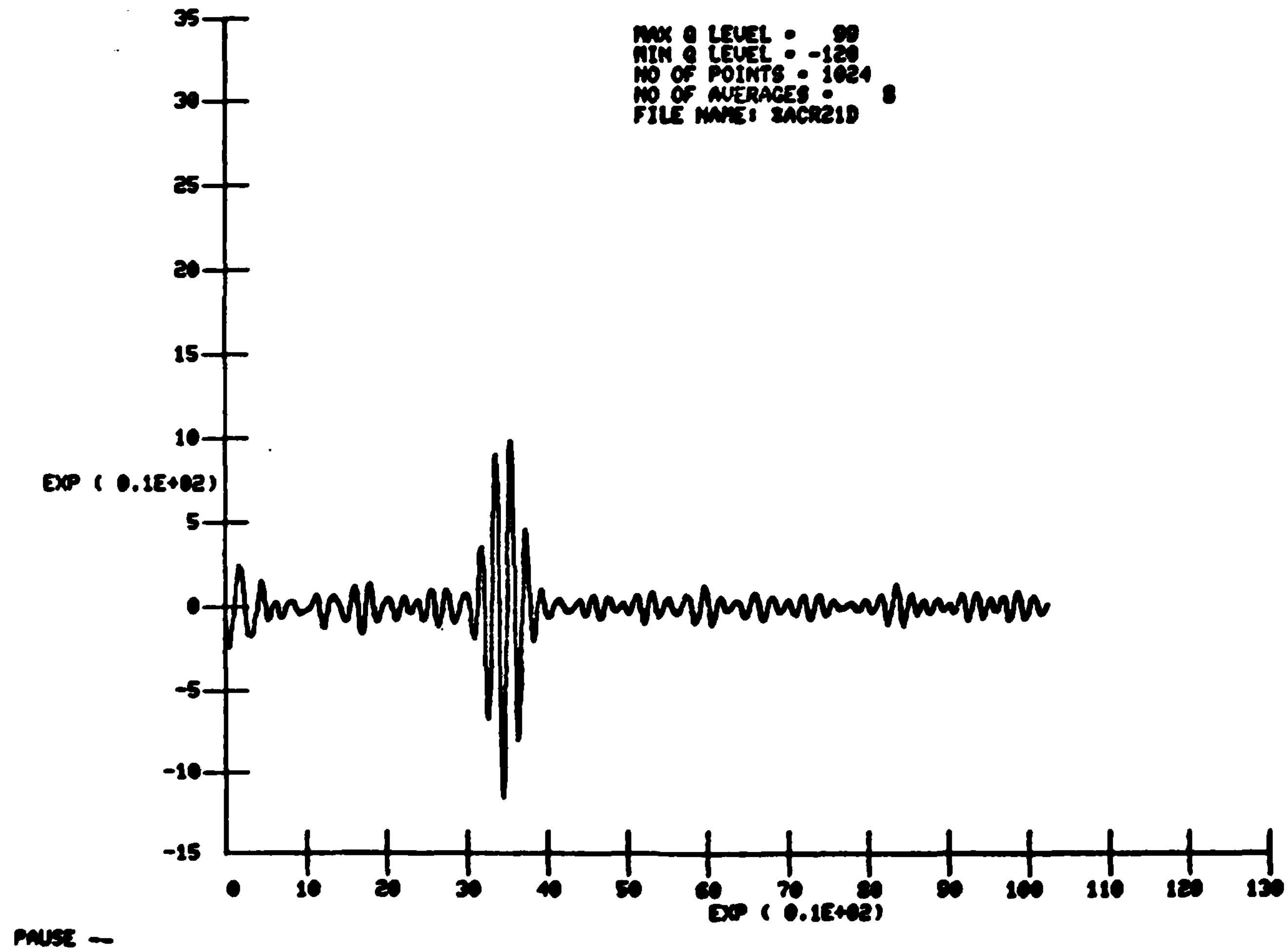

Figure A1-1. Crack Signal

A>KBN
ENTER GATE DELAY: 3950

FIRST GATE PEAK: 81.750000
SECOND GATE PEAK: 10.000000

RISE TIME = 82.0064
FALL TIME = 73.2225
PULSE DURATION =166.9283
PK-PK RATIO = 0.1223
HALF PULSE WIDTH=100.7912

2-SPACE PLOT PREDICTION: CRACK

ENTER FILE NAME: ACR21E

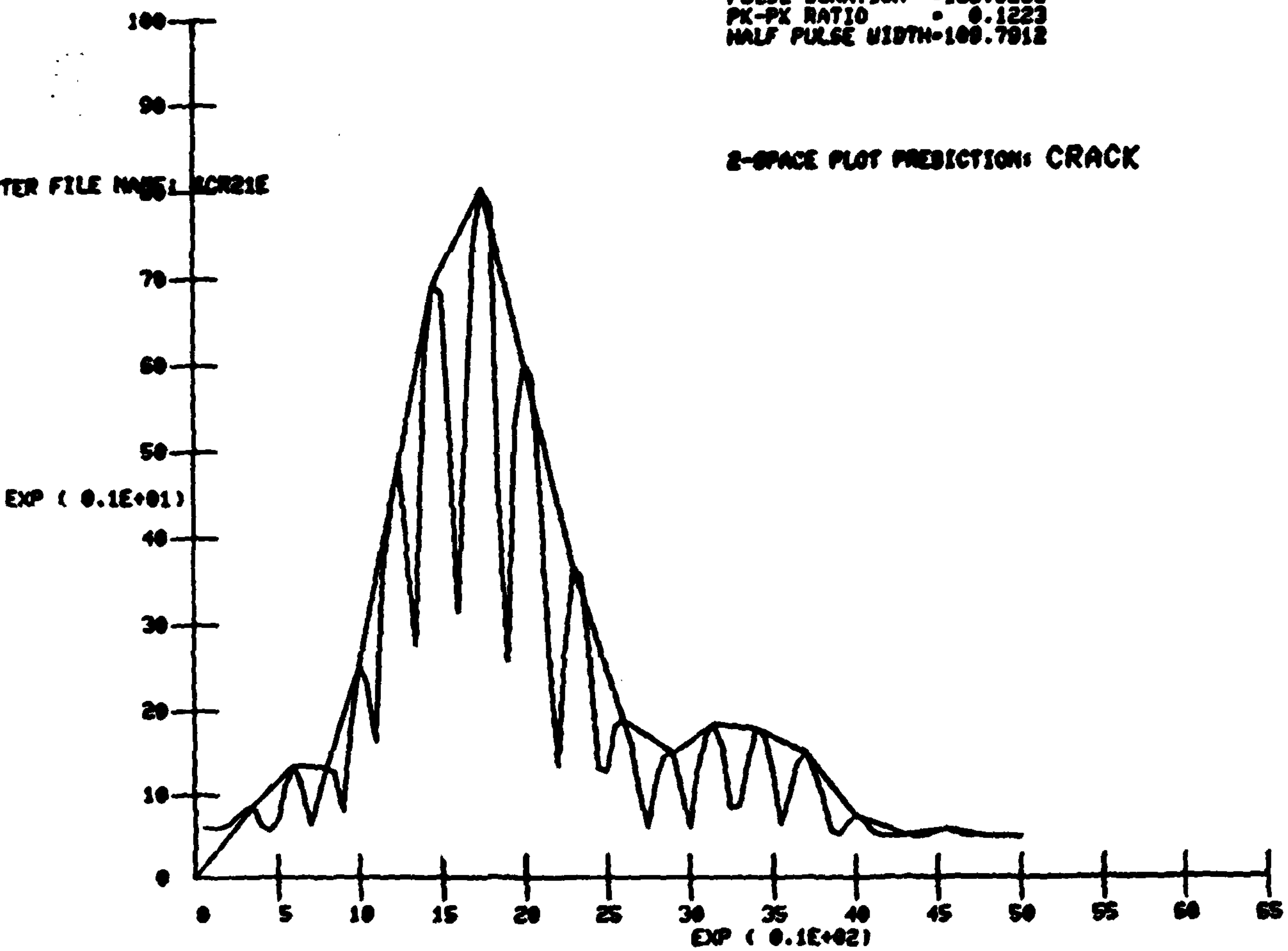

Figure AI-2. Prediction of Crack Signal

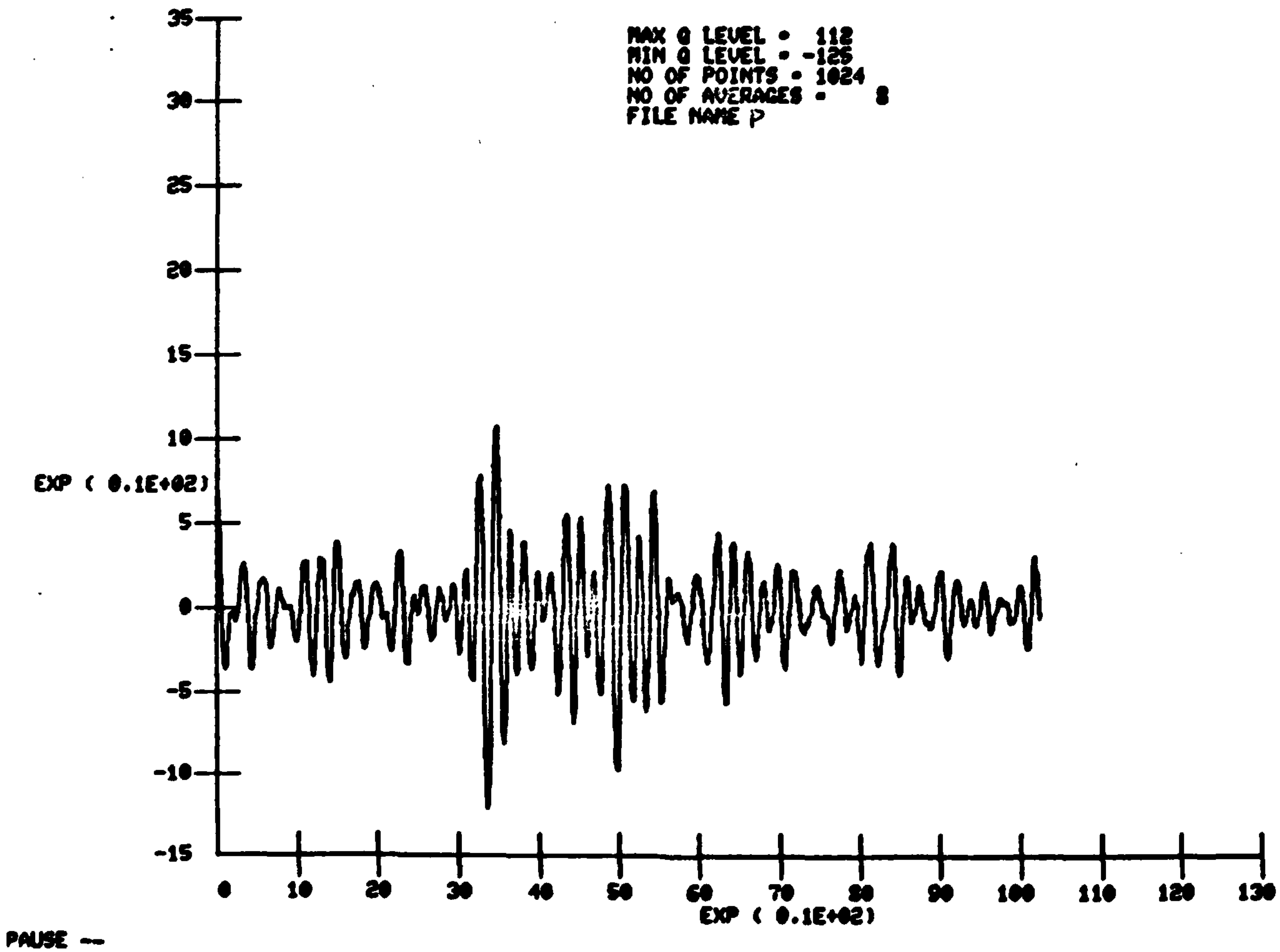

Figure A1-3. Porosity Signal

```
^C
.R KBN
ENTER GATE DELAY: 4900

FIRST GATE PEAK:    98.500000
SECOND GATE PEAK:   23.250000

RISE TIME        = 65.4056
FALL TIME        = 75.1235
PULSE DURATION   =168.8772
PK-PK RATIO      =  0.2350
HALF FULSE WIDTH=110.8276

ENTER FILE NAME: DX1:FP17D.DAT

2-SPACE PLOT PREDICTION: POROSITY
```

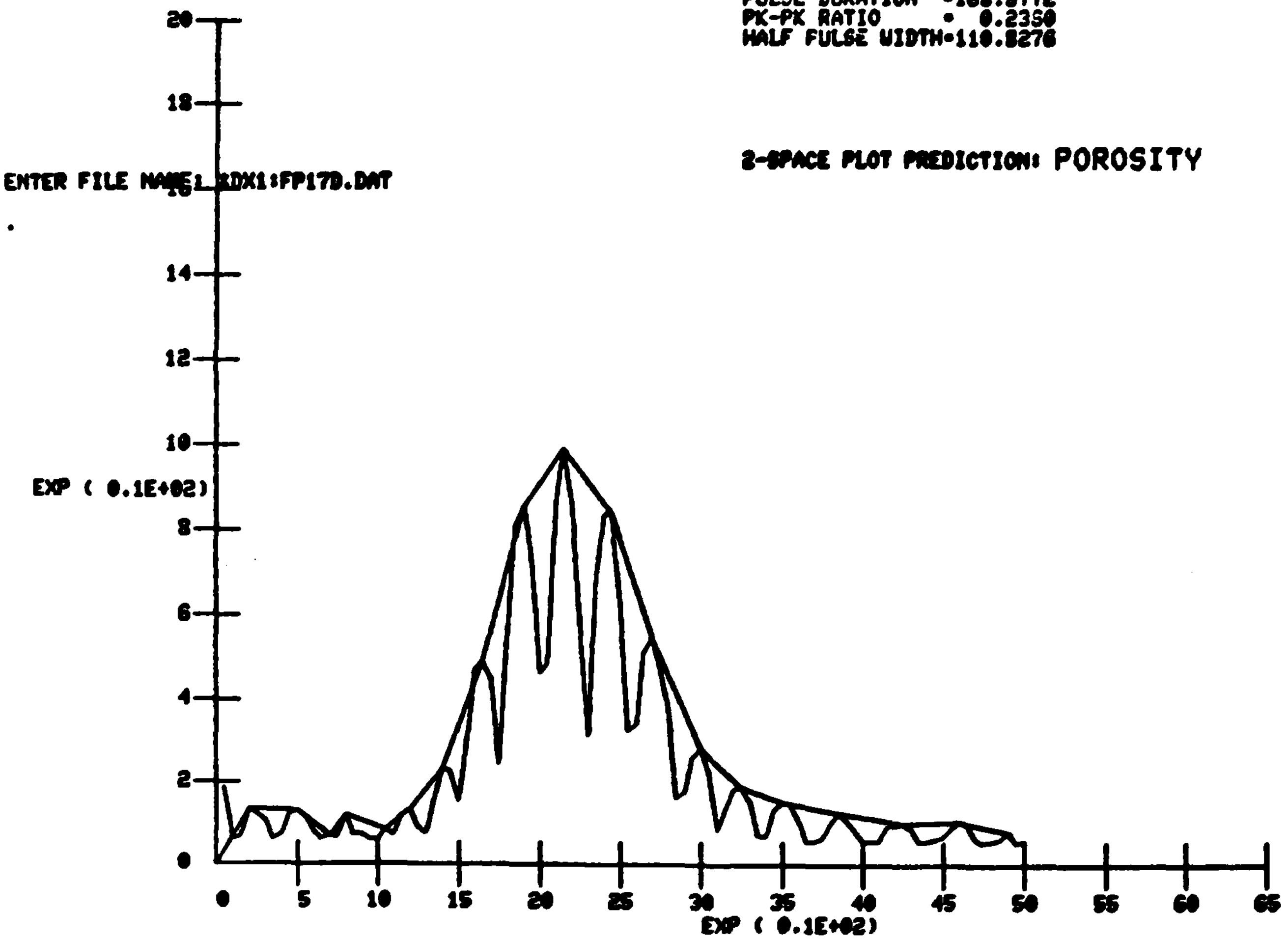

Figure A1-4. Prediction of Porosity Signal

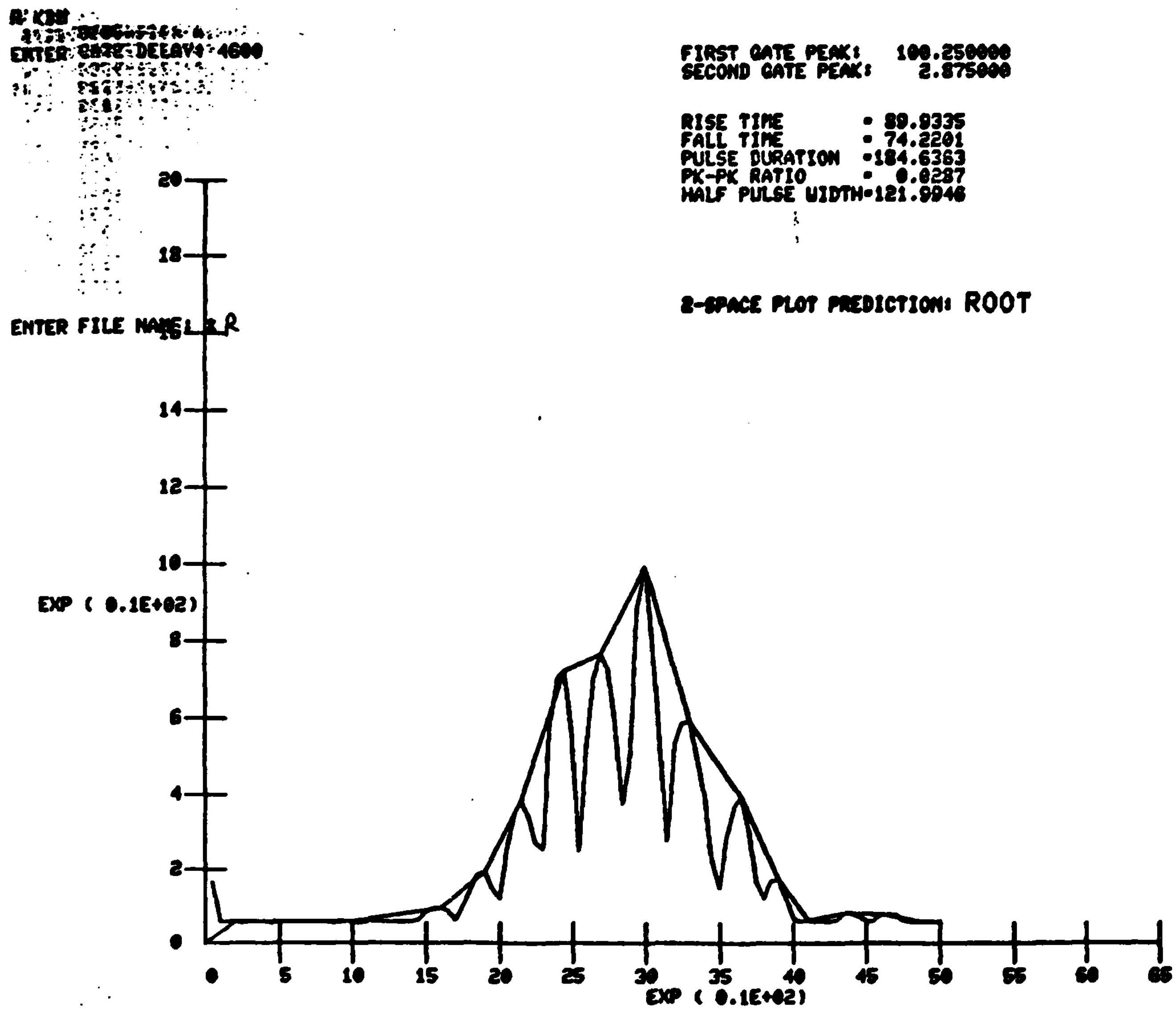

Figure A1-6. Prediction of Root Signal

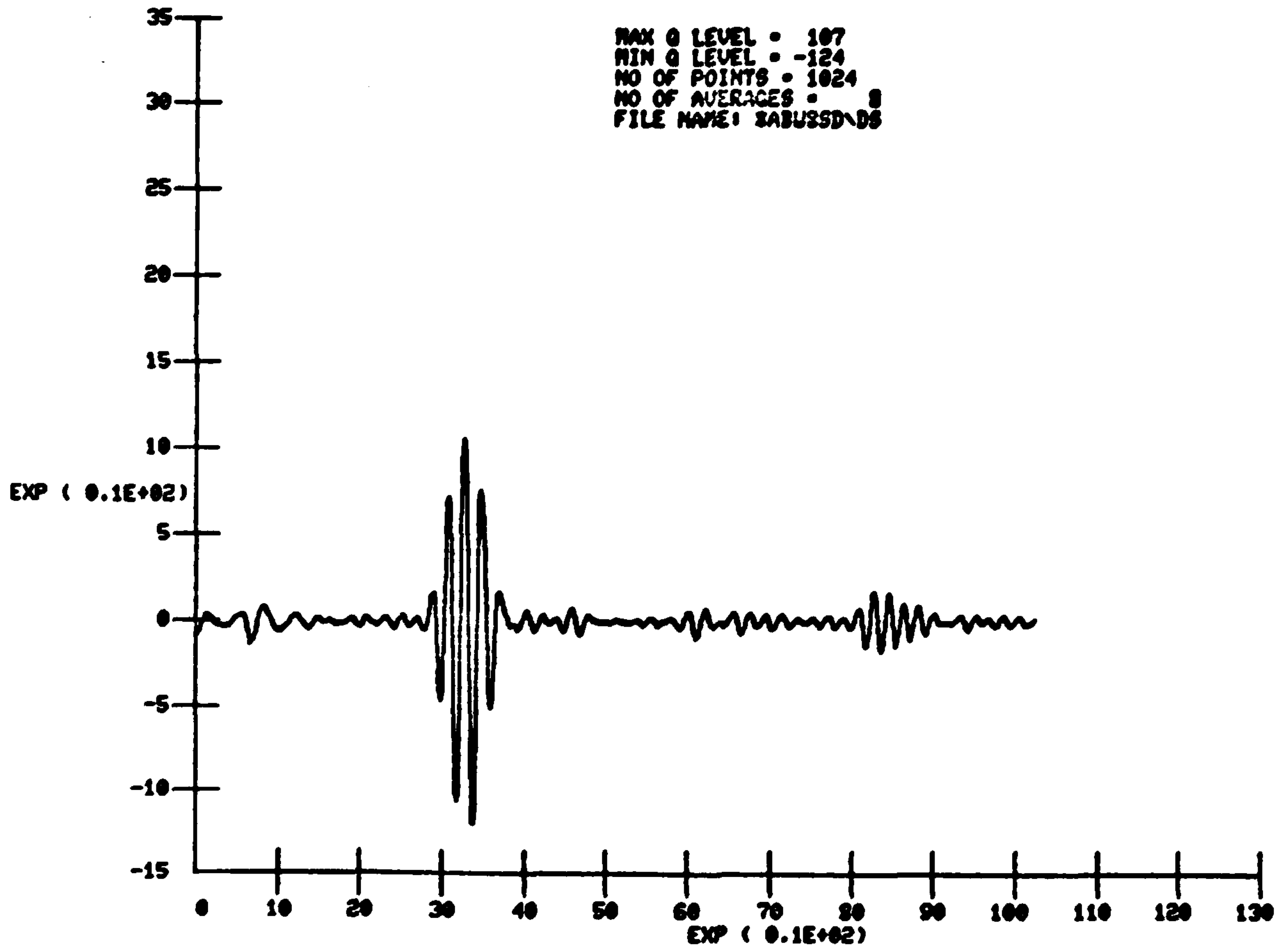

Figure A1-5. Root Signal

APPENDIX II

Some Novel Aspects of Weld Inspection

The purpose of this supplement is to relate some novel data acquisition procedures based on physics that could improve the sensitivity and specificity indexes of performance.

The first technique explored in this work was a modified tandem method. A diagram of the procedure is shown in Figure A2-1. From physics, it is expected that the echo received by transducer two would closely resemble the echo transmitted by transducer one. A smaller amplitude would be received at transducer two for a porosity defect. This happens because a crack reflection is specular in nature, whereas the porosity reflection is spherical in nature.

Further improvement can be made by studying an arc technique for acquiring data as illustrated in Figure A2-2. Again, the spherical scattering nature porosity is emphasized as the amplitude of the echo received by transducer two is approximately the same as the pulse echo amplitude received by transducer one. If the defect is a crack, however, a significant reduction in amplitude takes place at transducer two compared to one because of the specular type of directivity pattern from the crack type defect.

Experimental Procedure and Results

To verify what physics has shown, 32 reflectors from known defects were examined. The data acquisition procedure was done in three steps. First, a maximum signal was obtained from the transmit-receive transducer. This transducer was fixed to the weld plate. Amplitude of this signal and gain setting was recorded. Next, another transducer was placed in the tandem position to receive the maximum signal of the fixed transducer. The amplitude and gain setting was noted. Finally, a transducer was placed in the arc position, noting amplitude and gain setting. Position of the transducer is critical for accurate results.

The transmit-receive data was assigned a reference level of 0 dB. The gain for the tandem and arc methods was adjusted to this reference level. The mean and standard deviations of the gains needed to achieve the same relative amplitude

using the two techniques are shown in Table A2-1. This shows that a crack can be distinguished from a root defect using the tandem method and arc can be used to distinguish a crack from a porosity. A sorting tree algorithm is shown in Figure A2-3.

Implementation

This procedure could be implemented in the field. However, adjusting two transducers and a gain setting would be difficult and time consuming. A well designed "triple probe", such as that shown in Figure A2-4, would greatly ease the data acquisition. This probe would be fixed to the plate where maximum transmit-receive echo is obtained. The arc and tandem probes would then be adjusted for maximum amplitude. The gains would then be compared and the reflectors would be classified.

To further improve the implementation of this procedure, a microprocessor controlled flaw detector with multiple channels, movable gates, gain control, and peak detector could be used to ease data acquisition. In this system, the operator would find a reflector with the transmit-receive transducer and adjust the gain for a maximum amplitude. Then the microprocessor would calculate arrival times for the arc and tandem probes and set appropriate gates. The operator would adjust the probes for maximum signal amplitude in these gates. The microprocessor would compare these amplitudes and classify the defect.

Summary

A novel approach to weld inspection can be used to increase accuracy in flaw classification. However, this approach increases inspection time. A microprocessor can be used to speed up data acquisition and objectively make classifications. This study points out the importance of physics in acquiring data that will be used in advanced pattern recognition. There is no substitute for clever data acquisition based on physics. This, followed by pattern recog-

nition, will produce the best opportunity of successfully developing a flaw classification procedure and algorithm.

The overall sensitivity and specificity indexes of performance of this approach are approximately the same as those reported in the main body of the paper for the single element transducer data acquisition system. This occurs because of system and material noise as well as flaw variations from one position to another inside the welded plates

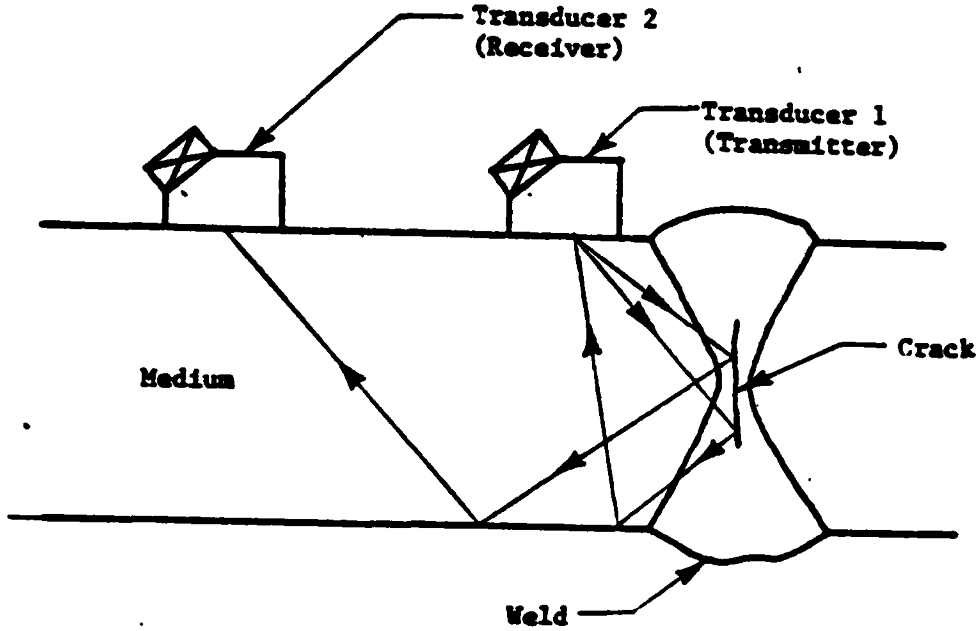

Figure A2-1. Tandem Probe

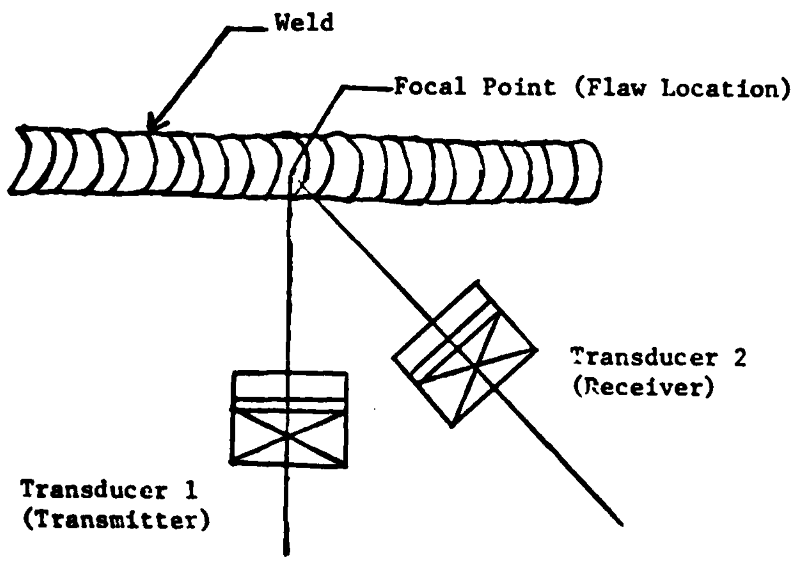

Figure A2-2. Arc Probe

Table A2-1. Experimental Results

	Tandom		Arc	
	Mean	Standard Deviation	Mean	Standard Deviation
Crack	5.8 dB	2.8 dB	17.0 dB	3.48 dB
Root	17.0 dB	1.7 dB	18.7 dB	.62 dB
Porosity	8.0 dB	2.6 dB	1.0 dB	.76 dB

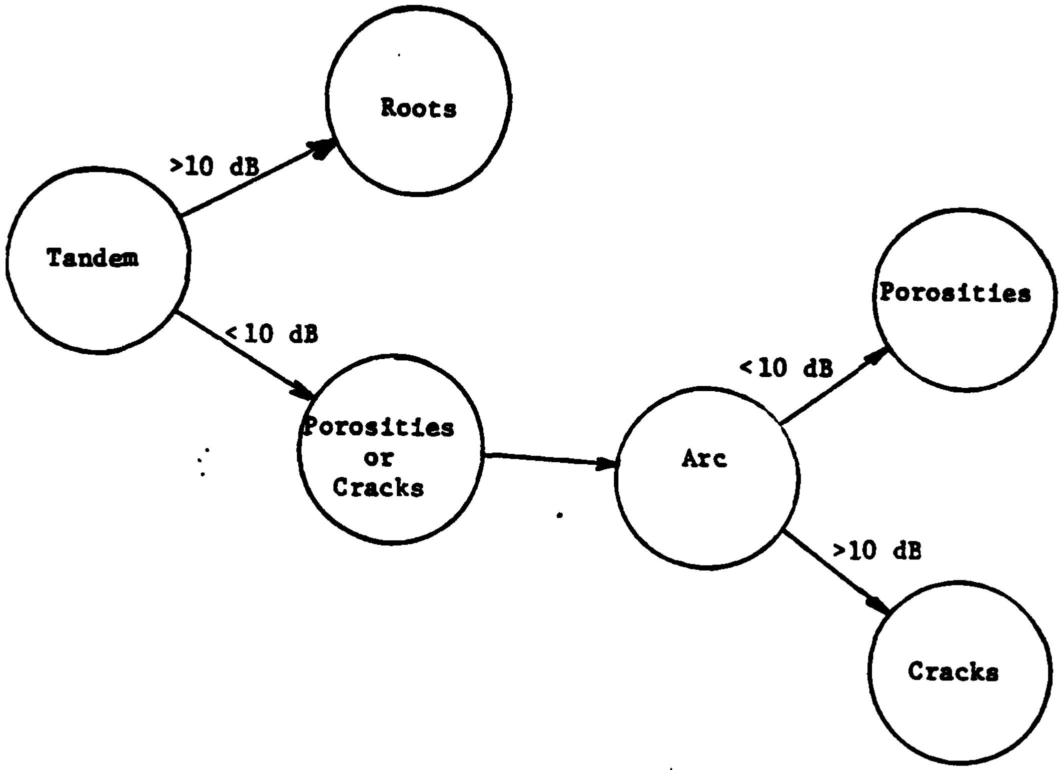

Figure A2-3. A Possible Sorting Algorithm

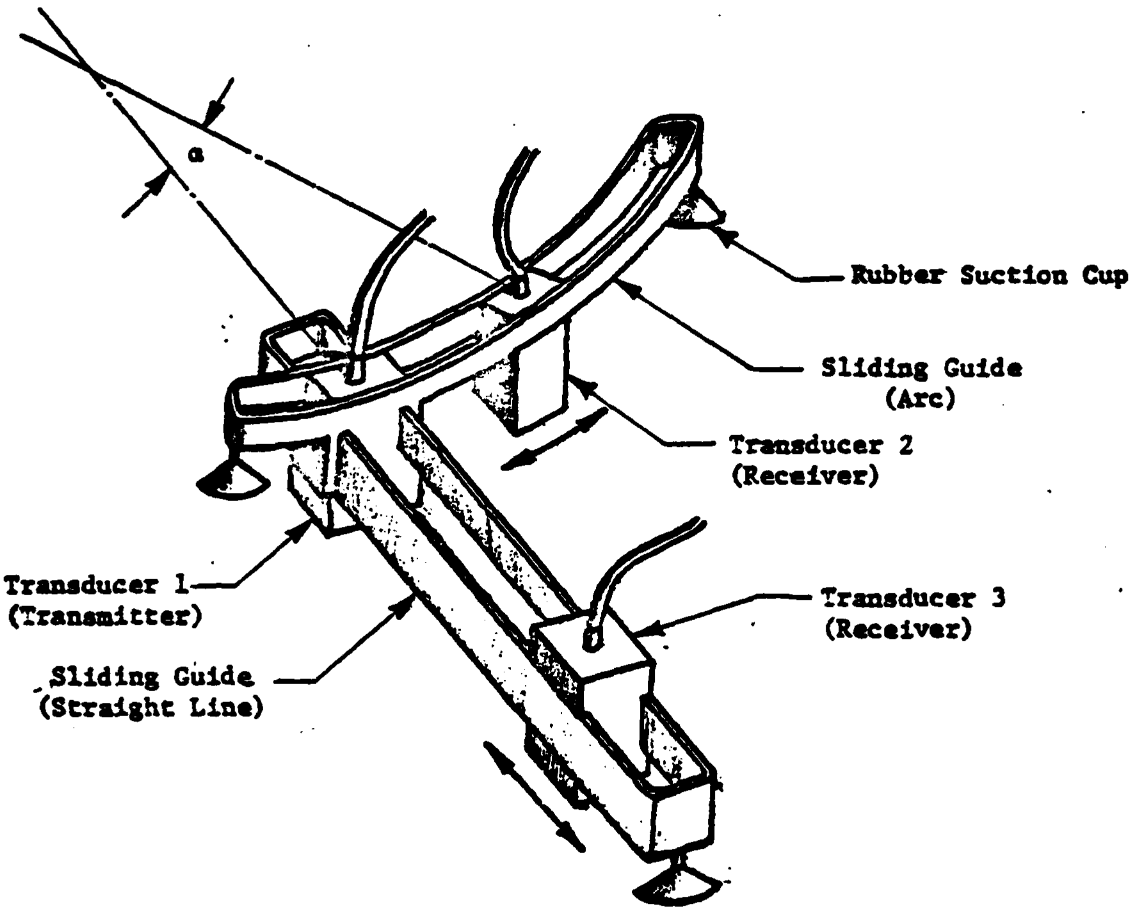

Figure A2-4. **Triple Probe Configuration**

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Flaw classification
Ultrasonics
Welded plate

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this paper is to manifest that a microprocessor, when utilized in connection with an ultrasonic flaw detector, can reliably regulate an ultrasonic inspection process. By virtue of several concentrated laboratory trials and accompanying analysis with the microprocessor-flaw detector combination, it will be demonstrated that dependable, speedy, and cost effective flaw detection is within the realm of reality.

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